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SUB-COOLED LIQUID HELIUM FLOW SUPPLY  
FOR DESIGN D MAGNET COOLING AT MDTF

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Abstract:

The parameters of the subcooled 4ATM helium flow from MDTF refrigerator and helium subcooler proposed to cool the SSC Design 'D' magnet is discussed. The system operating parameters are pressure = 4ATM and temperature = 4.35K. The higher than normal operating pressure is obtained by shutting down the cold turbine (T2) of MDTF refrigerator, and then not J-T the high pressure dense helium gas until after the magnet and liquid return line. The resultant helium temperature at the refrigerator outlet is described and the heat transfer tube length of the subcooler required to cool the flow to the ultimate desired temperature is evaluated.

Introduction:

Preliminary string tests of the six SSC Design 'D' magnets will be started May, 1986 at the Tevatron "ER" section. These magnets will be pre-tested and their magnetic performance evaluated at Magnet Development and Test Facility prior to installation.

Design 'D' magnets require high pressure subcooled single phase helium coolant which will be provided by MDTF's CTI-Sulzer 1500W helium refrigerator. Because 4ATM pressure is abnormally high, the maximum helium flow rate obtainable must be evaluated. Two relevant problems are investigated in this report.

1. Evaluation of the temperature at the outlet of the cold box with a helium output pressure of 4ATM or 5ATM.
2. Determination of the temperature profile of the helium stream in the subcooler and its suitability to cool the "SSC" long magnets. The subcooler is located in the MDTF distribution box.

High Pressure Helium Gas Stream in the Cold Box:

It is possible to obtain the high pressure ( $p = 4$  or  $5\text{ATM}$ ) cold helium gas with the cold turbine (T 2) of refrigerator shut down and isolated by valves or on. The reason for this turbine off running scenario is to protect the turbine from back pressure waves through the helium transfer tubes caused by a magnet quench.

The helium gas, after the heat exchanger #4 (Hx4), is expanded by the J-T process to  $4\text{ATM}$  and cooled by the heat exchanger #5 to  $7.08\text{K}$ . In this report, it is assumed that the heat exchanger #5 has the same cooling capacity of  $772\text{W}$  as it does in the regular operation. The helium gas cooldown process, after heat exchanger #4, is shown in Figure 1 for various possible operation scenarios,, including normal liquification mode used in 'Tevatron' testing operation.

1. Operation of cooling the SSC magnet: (turbine off:)  
A  $\rightarrow$  E: J-T expansion by the PCV-56 Valve

E  $\rightarrow$  F: heat exchanger No. #5

$$P_f = 4\text{ATM}; T_f = 7.08\text{K}$$

2. Regular Operation:

A  $\rightarrow$  B  $\rightarrow$  C  $\rightarrow$  D

He liquification:  $11.7\text{g/s}$  at  $4.42$

Cold turbine: working

Mass flow of helium gas is  $m = 65.5\text{g/sec}$  in each operation.

It is shown that the helium outlet temperature from the cold box is  $7.08\text{K}$  or  $7.41\text{K}$  and is indicated by the point "F" for a pressure of  $4$  or  $5\text{ATM}$  respectively. Suppose the required inlet helium temperature of design 'D' magnet is  $4.35\text{K}$ ; point "G", helium gas must be cooled in the subcooler from point F to G.

#### Heat Transfer in Helium Subcooler

Subcooler has three helically wound,  $240$  inch long, finned heat-transfer tubes. High pressure helium flows parallel in these tubes and is cooled by the liquid helium located outside shell. In order to cool the tube side stream to ~

4.35K, the shell side temperature must be lower than 4.35K. It is difficult to maintain the shell side temperature lower than 4.35K because of the pressure drop of the helium return to the cold box.

In this report, the bath or shell side temperature is 4.42K and 4.224K when the shell side pressure is 1.19ATM and 1.0ATM respectively. The heat transfer,  $dQ$ , between the (inside) tube side stream and (outside) shell side helium, is described for a length " $dx$ " along the axis of the tube as follows:

For tube side flow:

$$dQ = \pi D q_t dx$$

$$q_t = h(T_g - T_w)$$

Where  $T_g$  is the bulk temperature of helium;  $T_w$  is the wall temperature; and " $h$ " is the heat transfer coefficient between helium gas flow and finned tube. The value of " $h$ " is obtained from the equation of supercritical helium heat transfer shown in Fig. 2.

$$Nu = 0.024 Re^{0.6} Pr^{0.4}$$

For shell side heat transfer:

$$dQ = \phi A_r q_s dx$$

" $q_s$ " is obtained from Kutateradze correlation co-efficients for boiling heat transfer of liquid helium. Note that " $q_s$ " is a function of the temperature difference,  $\Delta T = T_w - T_L$ .  $T_w$  is the bottom temperature of fins, and " $a_r$ " is the outside surface area of the finned tube per unit length. " $\phi$ " is the fin co-efficient. Eq. (1) and eq. (4) combined yield the following expression:

$$q_t = [Qa_r / \pi D] q_s$$

The wall temperature of the finned tube, " $T_w$ " (i.e. which is the bottom fin temperature as well) and the heat transfer  $dQ/dx$  are obtained from eq. (5) for the different  $T_g$ . (Figures 4 and 5)

Enthalpy decrease  $di$  of the tube side helium flow is related to the heat transfer  $dQ/dx$  and total mass flow " $m$ " in the following relationship:

$$m/n \, di/dx = dQ/dx$$

Where " $n$ " is the number of finned tubes ( $n=3$ ). The finned tube length " $dx$ " to cool the helium flow by " $di$ " is obtained from eq. (6).

Figures 6 and 7 show the cooldown of the helium in the subcooler for pressures  $P_t = 4\text{ATM}$  and  $5\text{ATM}$  respectively. The  $4\text{ATM}$  helium flow is cooled to  $4.62\text{K}$  at the subcooler outlet when the (bath) shell side temperature is  $4.42\text{K}$ . If  $4.35\text{K}$  is required for the inlet temperature of the design "D" magnet, then another subcooler, contained in the feed can, will be necessary. This subcooler is now under construction and has 6 finned tubes of the same size as that of the MTF subcooler. Figure 8 shows the temperature reduction of the helium stream in the second feedcan subcooler. If the inlet temperature is  $4.62\text{K}$ , helium flow can be cooled to  $4.35\text{K}$  in 71 inches along the heat transfer tube at shell side (bath) temperature of  $4.22\text{K}$ .

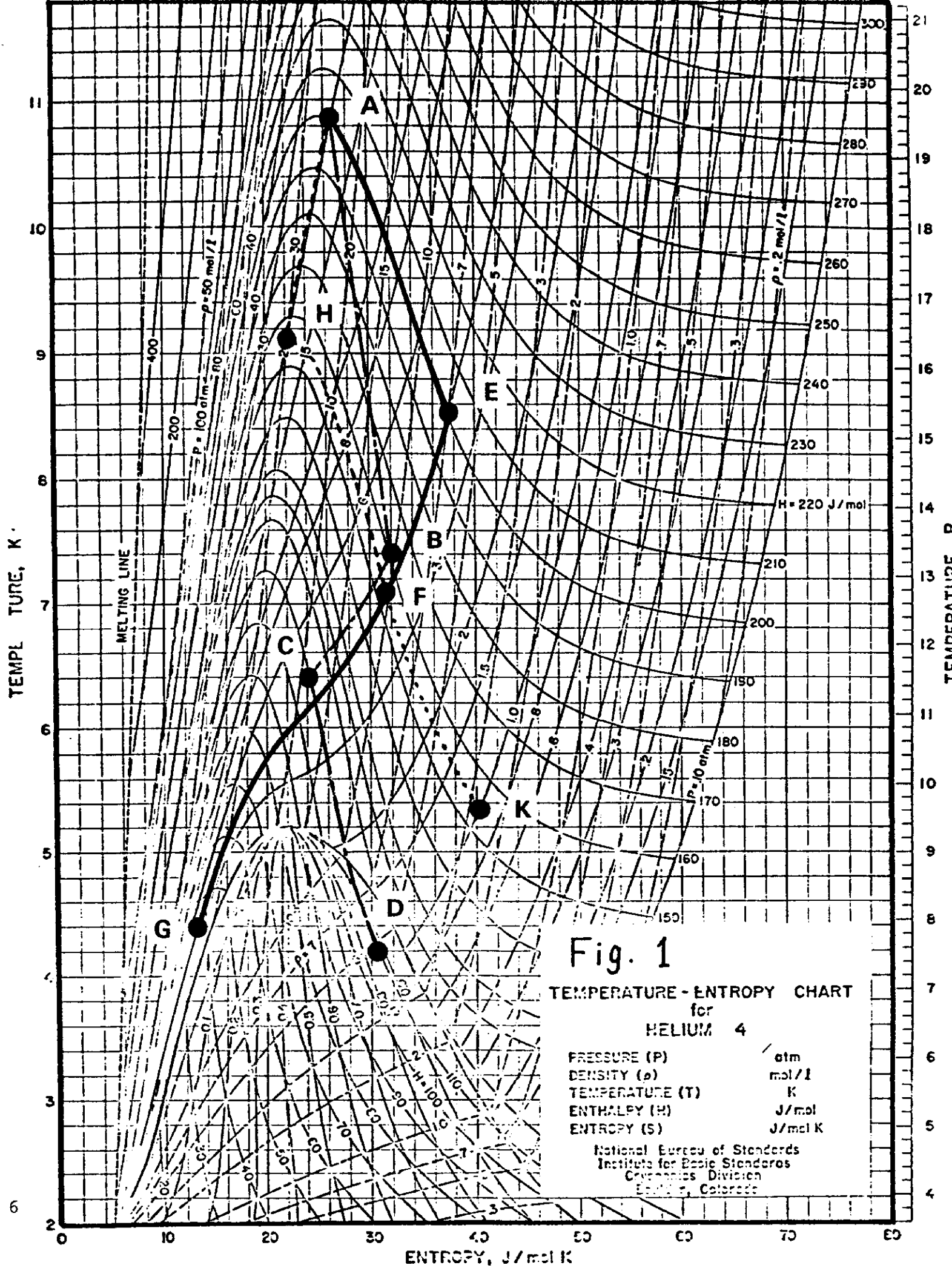
An alternate way to obtain a helium temperature of  $4.35\text{K}$  is to employ a cold pump for the compression of the return flow from the subcooler shell side to the refrigerator cold box. In this case, the pressure of the subcooler shell side will be subatmospheric.

If the pressure of the helium flow for magnet cooling is raised to  $5\text{ATM}$ , its outlet temperature at the cold box increases to  $7.41\text{K}$ . But, this flow can be cooled to  $4.41\text{K}$  or  $4.58\text{K}$  by a shell side bath subcooler  $4.224\text{K}$  or  $4.42\text{K}$  temperature respectively. This is because the specific heat  $C_p$  of helium is much lower around the transposed critical region,  $5\text{ATM}$ , than at  $4\text{ATM}$ . The total mass flow rate is assumed to be the same value  $65.5\text{g/sec}$  in each case.

#### Conclusion:

The helium operating the SSC design "D" magnet can be cooled to  $4.62\text{K}$  or  $4.58\text{K}$  by MTF subcooler when the pressure of the flow is  $4\text{ATM}$  or  $5\text{ATM}$  respectively and the subcooler shell side temperature is  $4.42\text{K}$ . The maximum total mass flow rate and still to operate with these parameters is  $65.5\text{g/sec}$  that can be supplied by the MTF refrigerator. Apparently, one more subcooler will be necessary if the design "D" magnet is to be cooled to  $4.35\text{K}$  or below.

The feedcan subcooler now under construction, which has 6 heat transfer tubes each of the same size as that of the MTF subcooler finned tubes which is certainly adequate. The helium flow after the MTDF subcooler can be cooled to 4.35K in just 71 inches of heat transfer tube length which is only 30% of the length available.



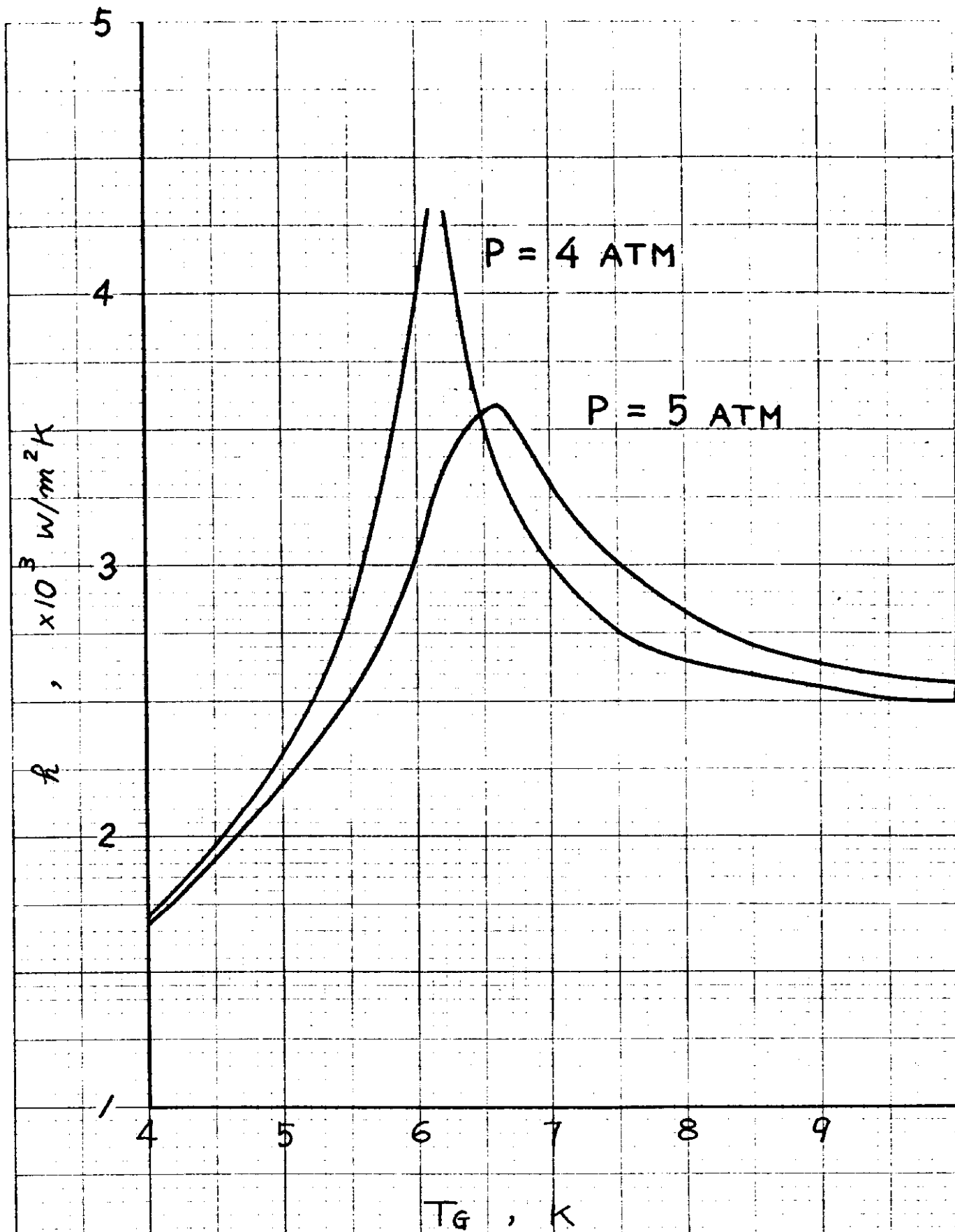


Fig2 HEAT TRANSFER COEFFICIENT OF HELIUM  
FLOW IN SUBCOOLER ( $\dot{m} = 65.5 \text{ g/s}$ ,  $n = 3$ )



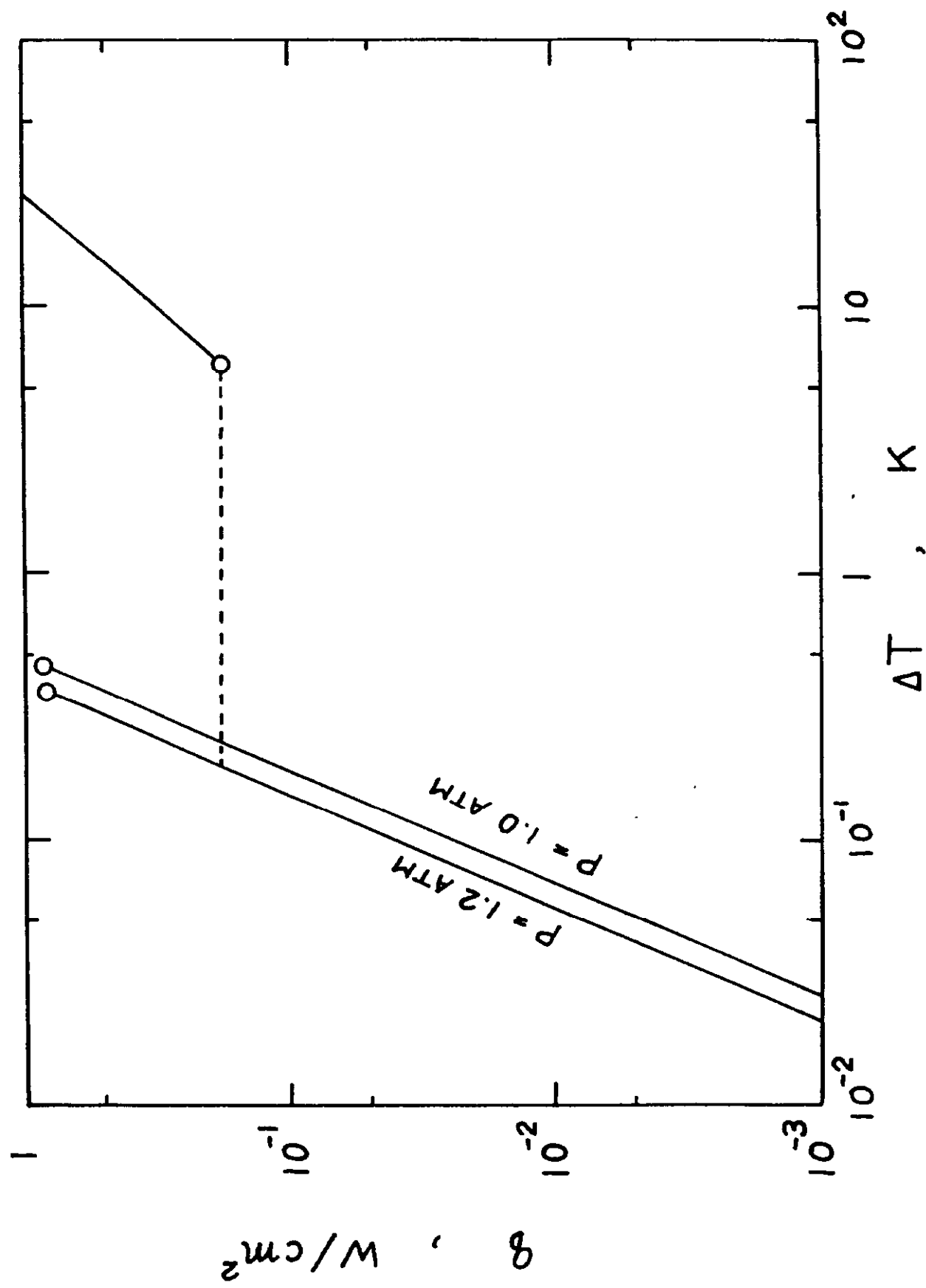


Fig.3 Predictive nucleate and film pool boiling correlations for helium

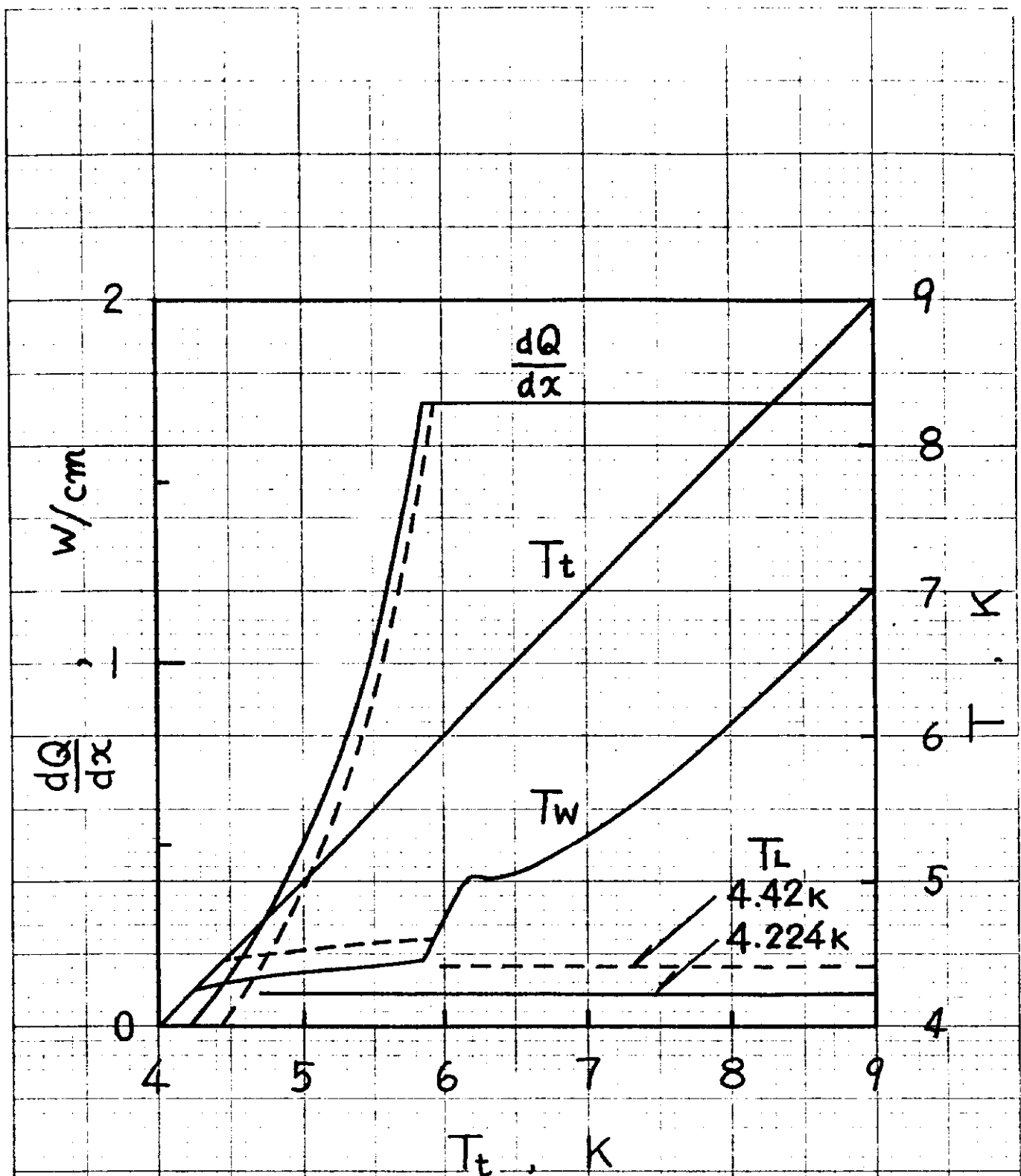


Fig.4 Tube-side Temperature  $T_t$  v.s. Heat Transfer  $\frac{dQ}{dx}$  and Wall Temperature  $T_w$  in MTDF Subcooler  
(shell-side temp.; — 4.224 K, --- 4.42 K, tube-side press.; 4 ATM)

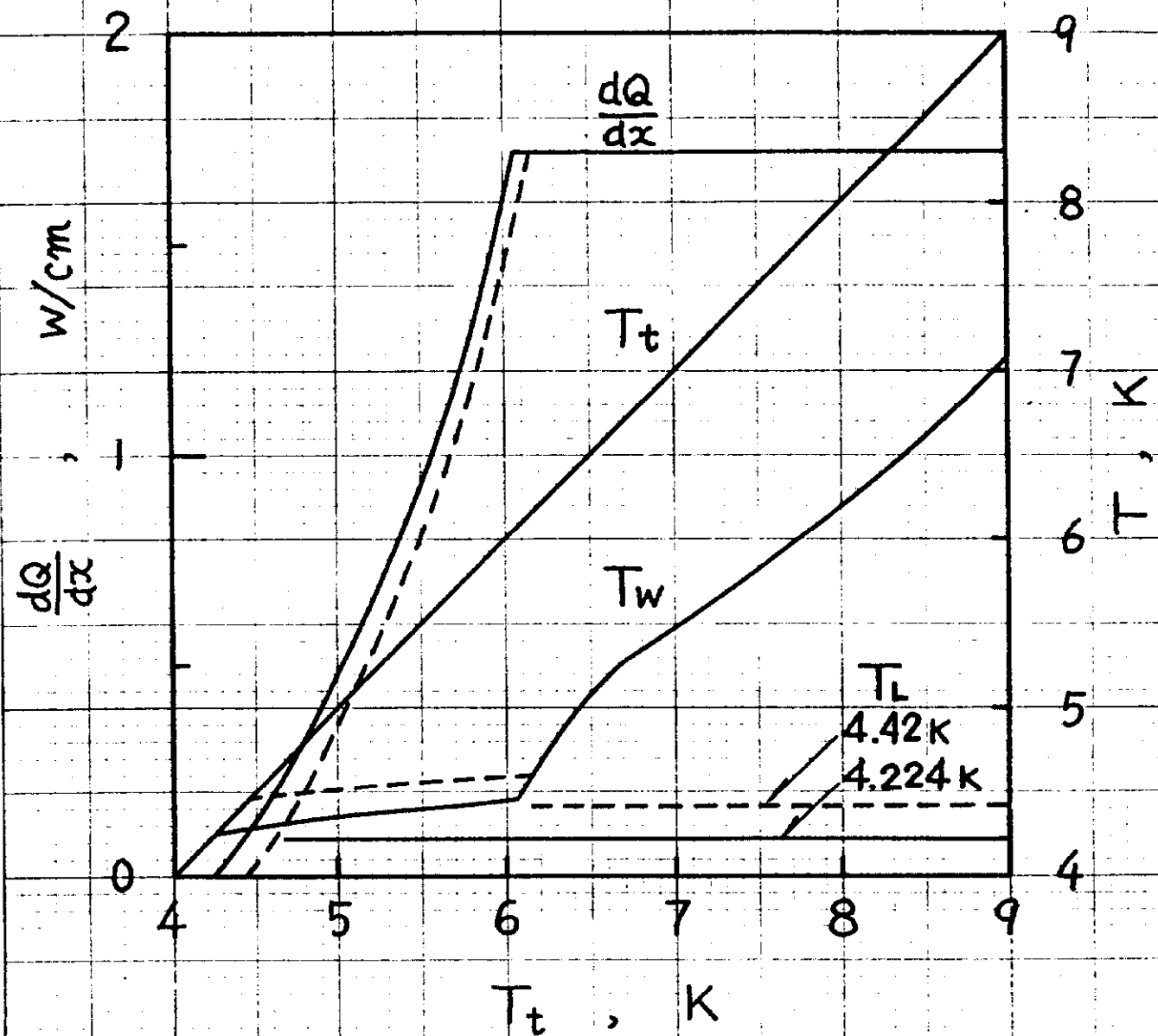


Fig.5 Tube-side Temperature  $T_t$  v.s. Heat Transfer  $\frac{dQ}{dx}$  and Wall Temperature  $T_w$  in MTD Subcooler  
(shell-side temp. ; — 4.224K, --- 4.42K, tube-side press. ; 5ATM)

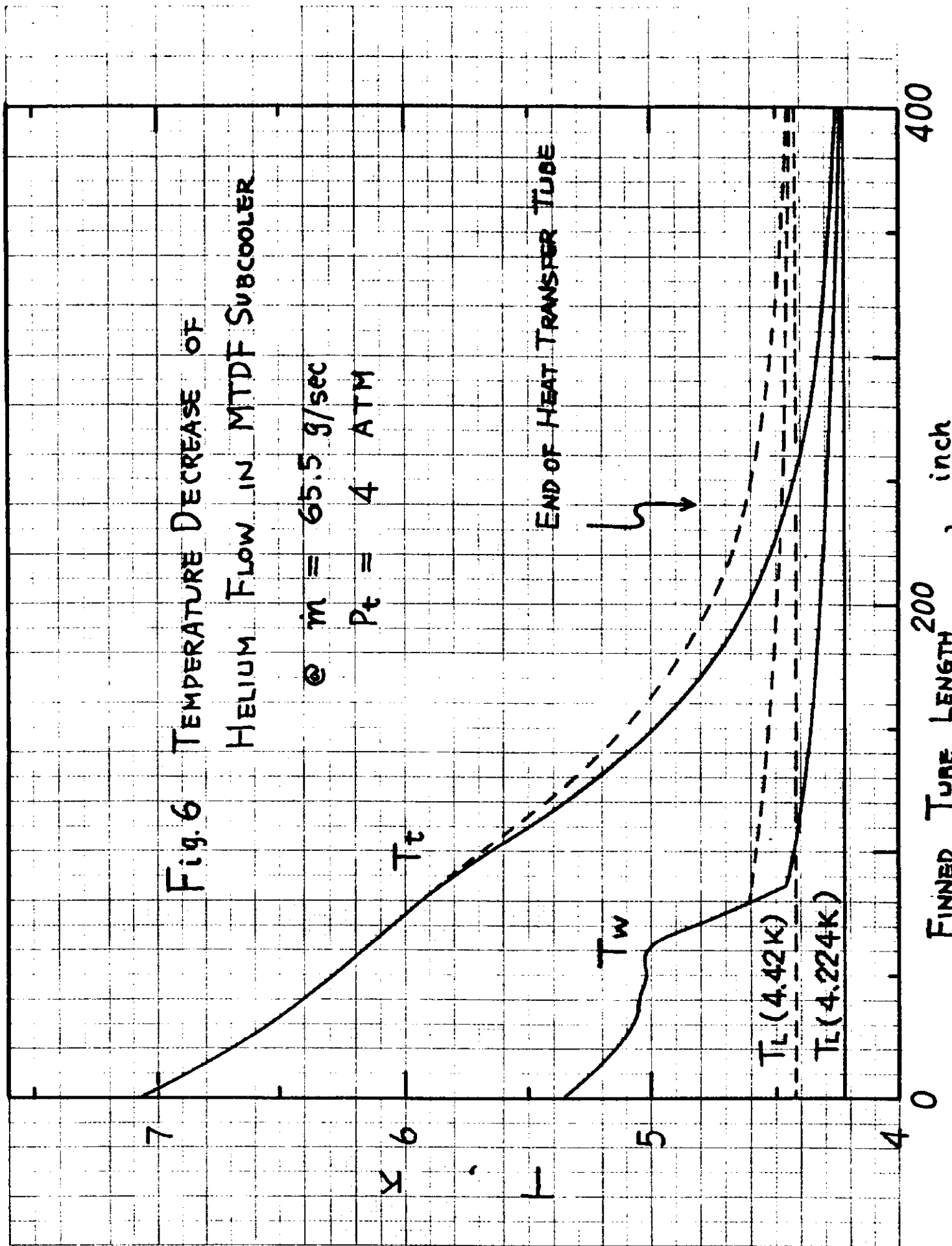
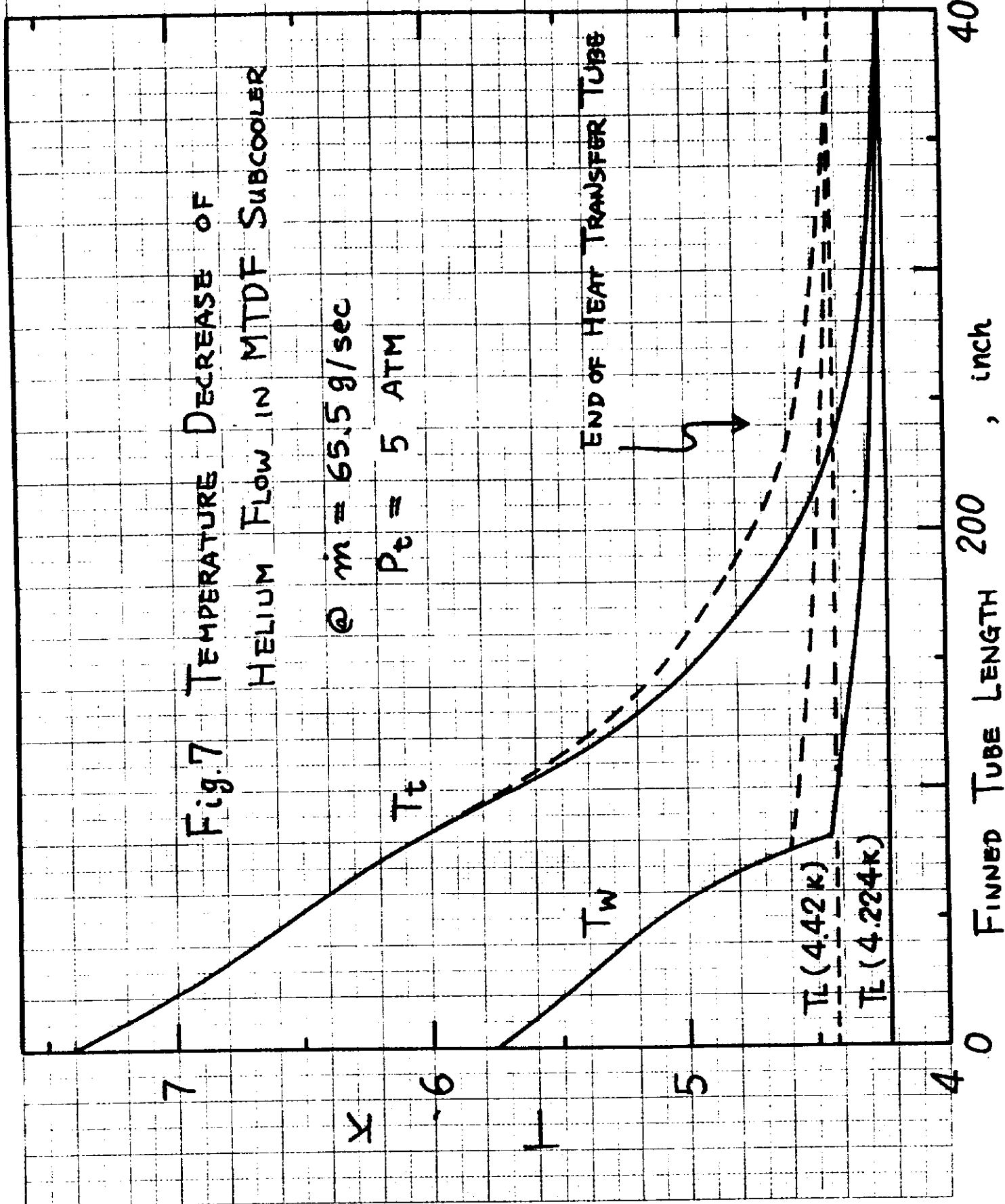


Fig. 7 TEMPERATURE DECREASE OF  
HELIUM FLOW IN MTD F SUBCOOLER

@  $\dot{m} = 65.5 \text{ g/sec}$

$P_t = 5 \text{ ATM}$

END OF HEAT TRANSFER TUBE



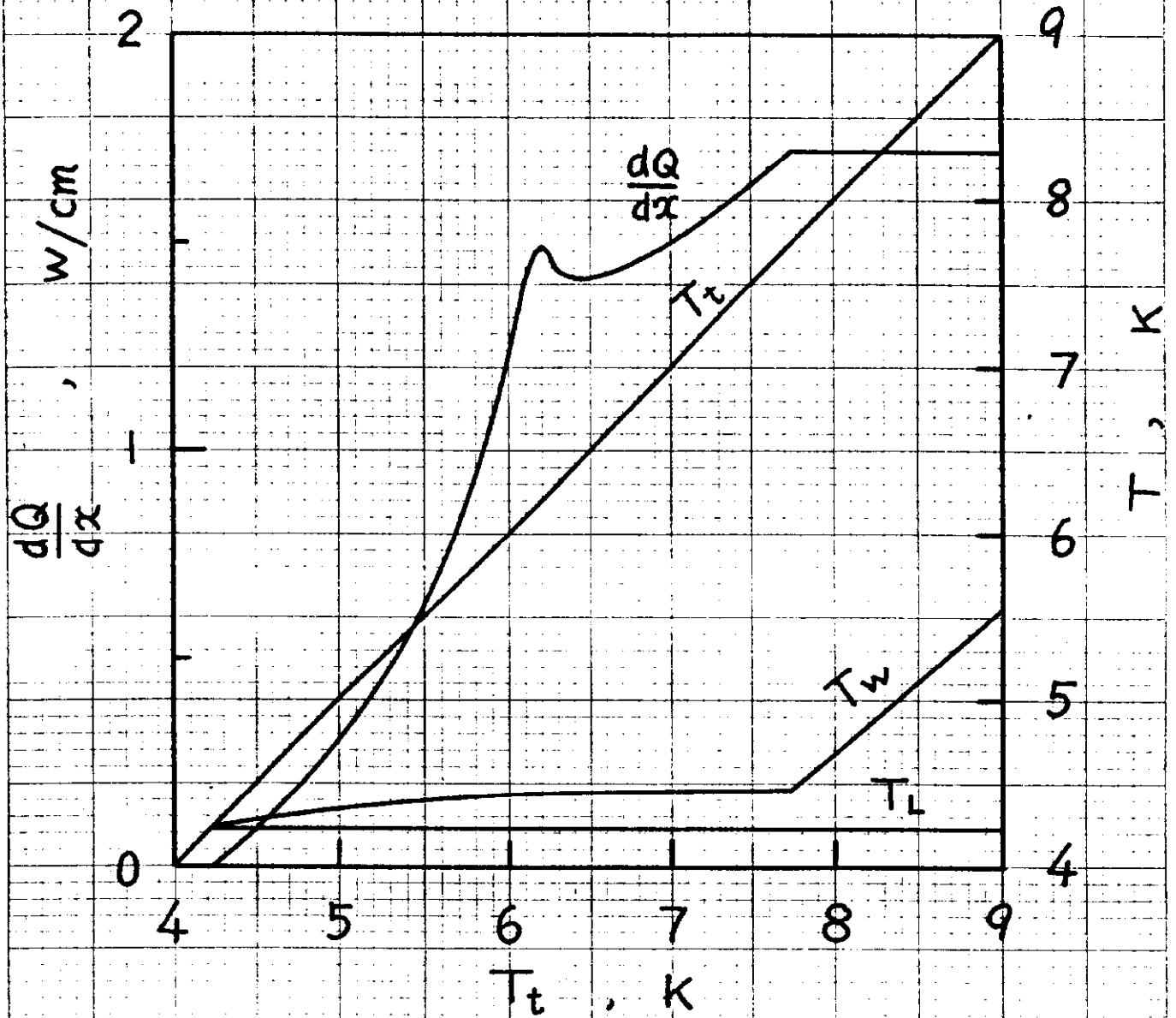


Fig. 8 Tube-side Temperature  $T_t$  v.s. Heat Transfer  $\frac{dQ}{dx}$  and Wall Temperature  $T_w$  in Feed Can Subcooler (shell-side temp.  $T_L = 4.224\text{K}$ , Tube-side press.  $P_t = 4\text{ATM}$ )

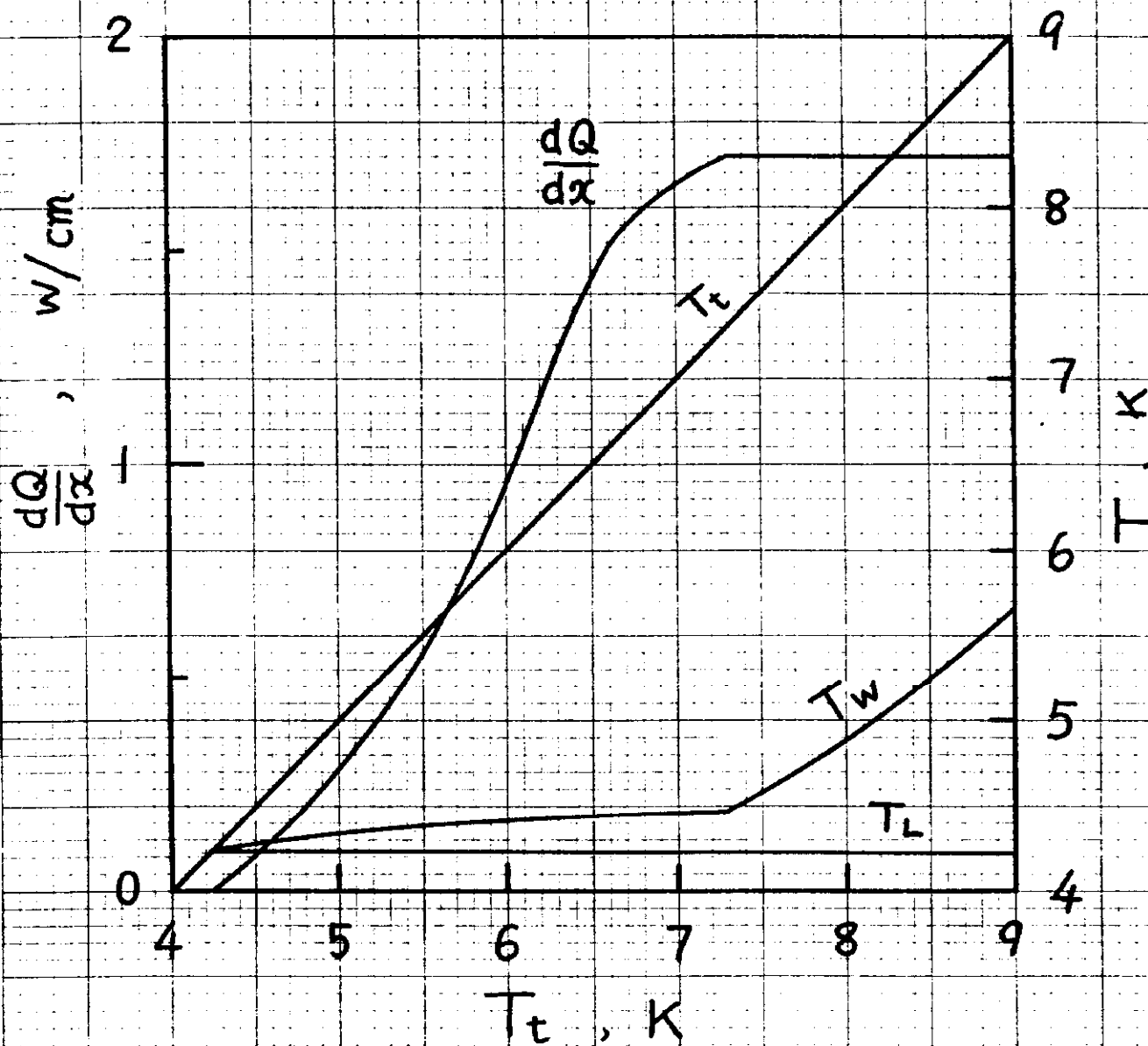


Fig. 9 Tube-side Temperature  $T_t$  v.s. Heat Transfer  $\frac{dQ}{dx}$  and Wall Temperature  $T_w$  in Feed Can Subcooler  
(shell-side temp.  $T_L = 4.224\text{K}$ , tube-side press.  $P_t = 5\text{ATM}$ )

Fig 10 HELIUM FLOW COOL DOWN  
IN FEED CAN SUBCOOLER

@  $\dot{m} = 65.58/s$   
 $T_L = 4.224 K$

